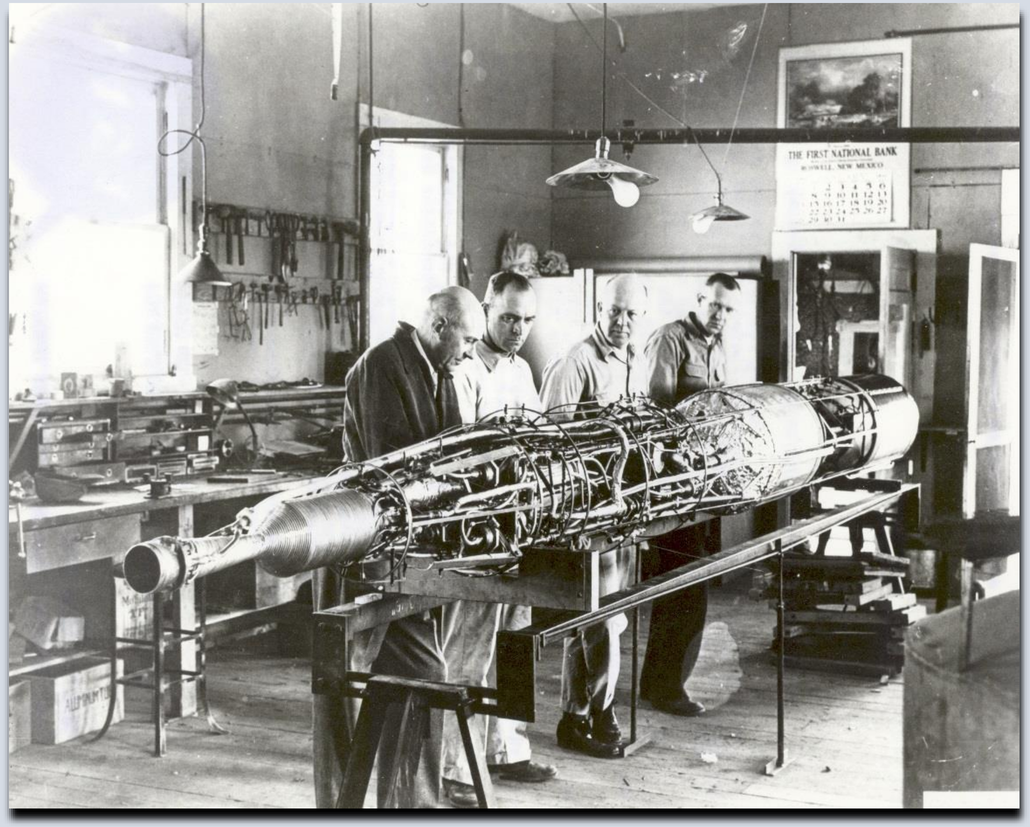


Human Exploration and Operations Committee

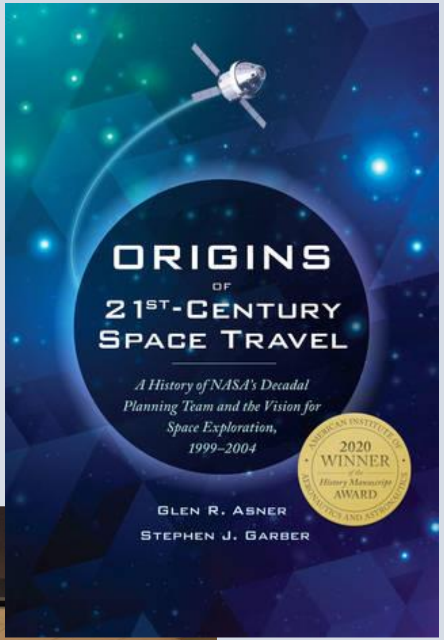
NASA Advisory Council

May 31, 2019

N. Wayne Hale, Jr.

HEO Committee Activities since May 2019

- Reading material: Origins of 21st Century Space Travel
- Briefings on alternative architectures
- Fact Finding tour and meetings at MAF and SSC



HEO Committee Briefings

- Janet Karika – Chief of Staff, HQ - status of NSpPC Actions
- Ken Bowersox – Acting AA HEOMD, HQ – HEO update
- Sam Scimemi – ISS Deputy AA, HQ – ISS Update
- Bill Wrobel – SLS Green Run Manager, HQ – Green Run background and plans
- Tom Whitmeyer – Exploration Systems, Deputy AA, HQ – ESD update
- Marshall Smith – Advanced Exploration Systems, Deputy AA, HQ – AES Update
- Doug Comstock – LEO Commercialization Manager, HQ – Commercialization update
- Mike Kincaid – STEM Engagement and Outreach AA, HQ – STEM program updates
- Program Managers
    - John Honeycutt – SLS Program Manager, MSFC
    - Mark Kirasich – Orion Program Manager, JSC
    - Kathy Leuders – Commercial Crew Program, KSC
    - Amanda Mitsckevitch – Launch Services Program, KSC

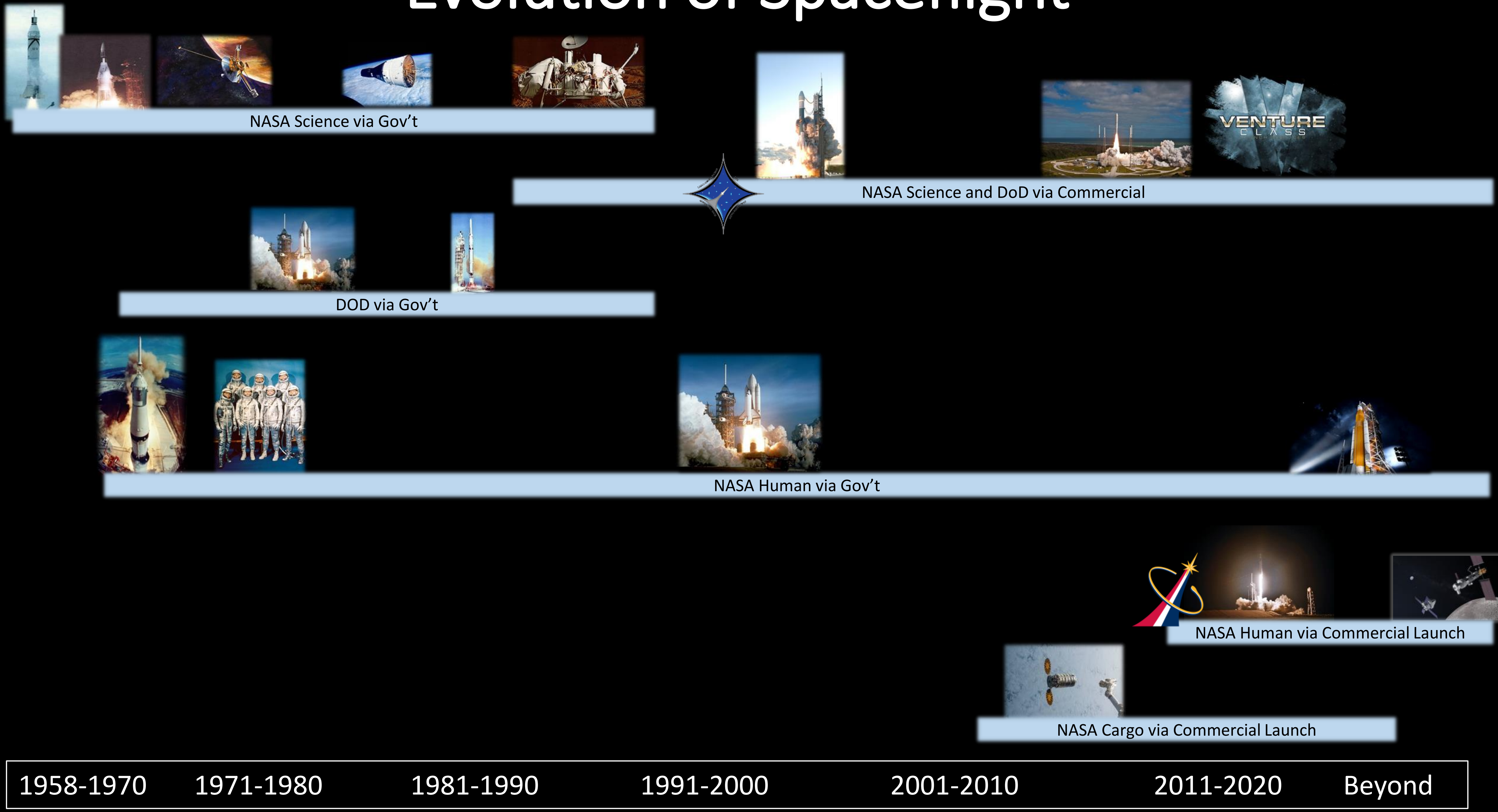
- Mark Rodgers/Steven Edwards – Advanced Analysis Group, MSFC

NAC HEO Chairman Activities

- Represented NAC at ASAP Meeting in September at JSC

- Individual meetings with leadership:
  - Lisa Watson-Morgan – Human Lander Systems Program Manager, MSFC
  - Dan Hartman – Gateway Program Manager, JSC
  - Kirk Shireman – ISS Program Manager, JSC
  - Kathy Lueders – Commercial Crew Program Manager, KSC
  - Center Directors:
    - Mark Geyer – JSC
    - Jody Singer – MSFC
    - Bob Cabana – KSC
    - Rick Gilbrech - SSC
  - Others

Evolution of Spaceflight

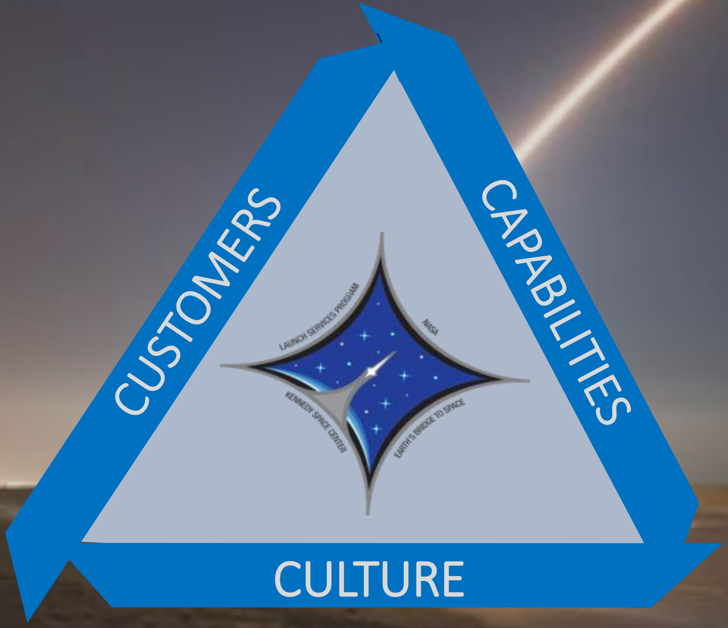


LSP Mission:

Uniting customers, capabilities, and culture to explore space through unparalleled launch services

LSP Vision:

Science and discovery through unlimited access to the universe



Goals

Maximize Mission Success

Assure Long-Term Launch Services

Promote Evolution of a US Commercial Space Launch Market

Continually Enhance LSP's Core Capabilities

LAUNCH SERVICES PROGRAM PARTNERS

TDRS

NOAA

Commercial Resupply

NASA Goddard Space Flight Center

COMMERCIAL CREW PROGRAM

CSA ASC

ARTEMIS

Science Mission Directorate

USGS science for a changing world

JPL Jet Propulsion Laboratory California Institute of Technology

Space Technology Mission Directorate

SPACE LAUNCH SYSTEM

NASA Johnson Space Center

NASA Langley Research Center

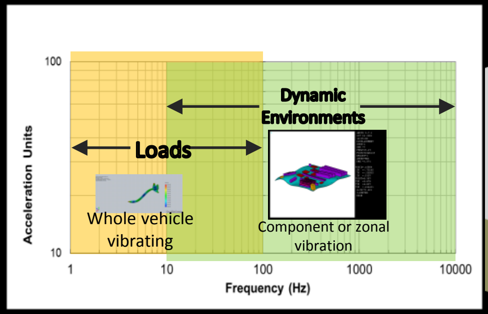
NASA Marshall Space Flight Center

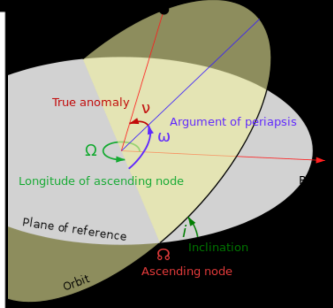
DLR

Traditional LSP Roles and Responsibilities

Acquire Launch Services

Verify and validate
mission engineering and analysis





Manage launch vehicle to
spacecraft integration

Certify launch systems
for NASA use

Insight and approval of production,
integration, testing and processing

U.S. Manifest Coordination thru CLSRB

LSP Fleets

Northrop Grumman


Pegasus XL


Minotaur C


Antares

United Launch Alliance


Atlas V

Delta II


Delta IV Heavy

SpaceX


Falcon 9


Falcon Heavy

Venture Class Launch Services


Launcher One


Electron

Emerging Vehicles


Firefly


Terran 1

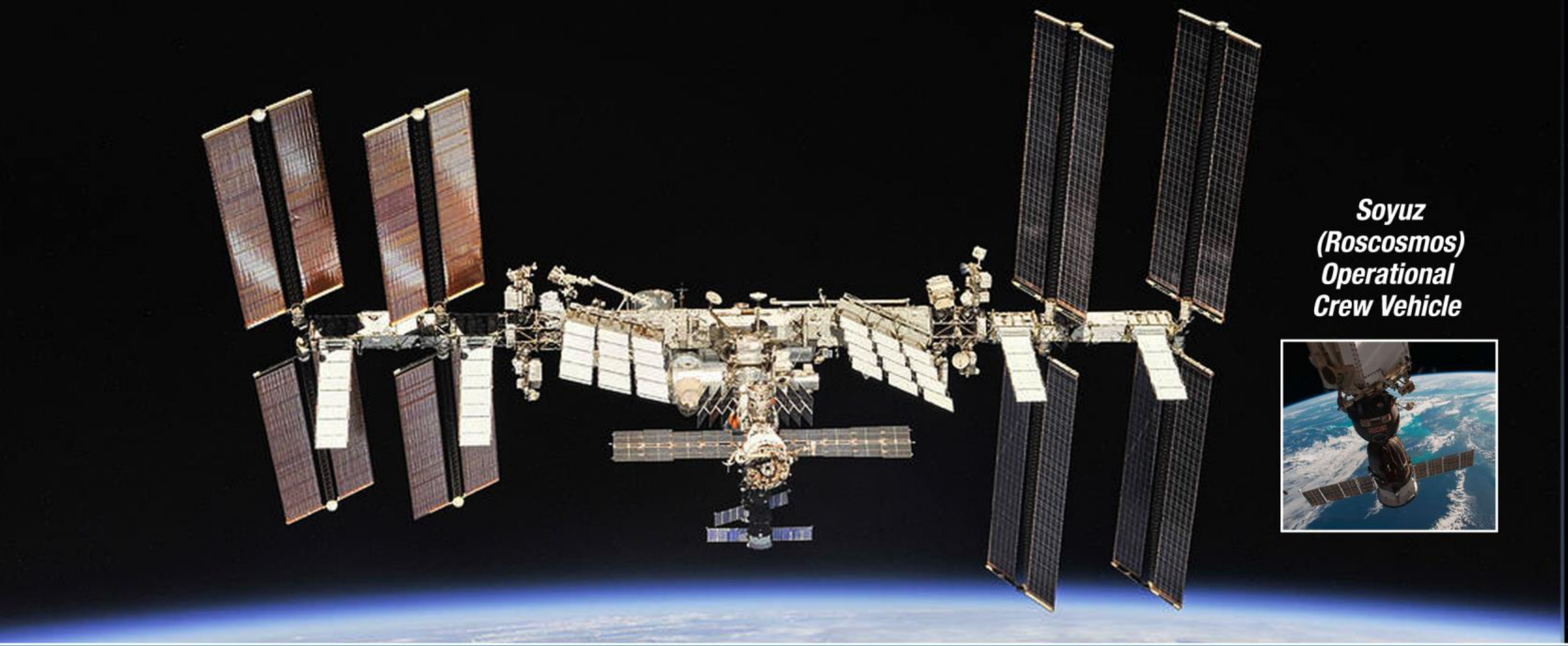
New Glenn

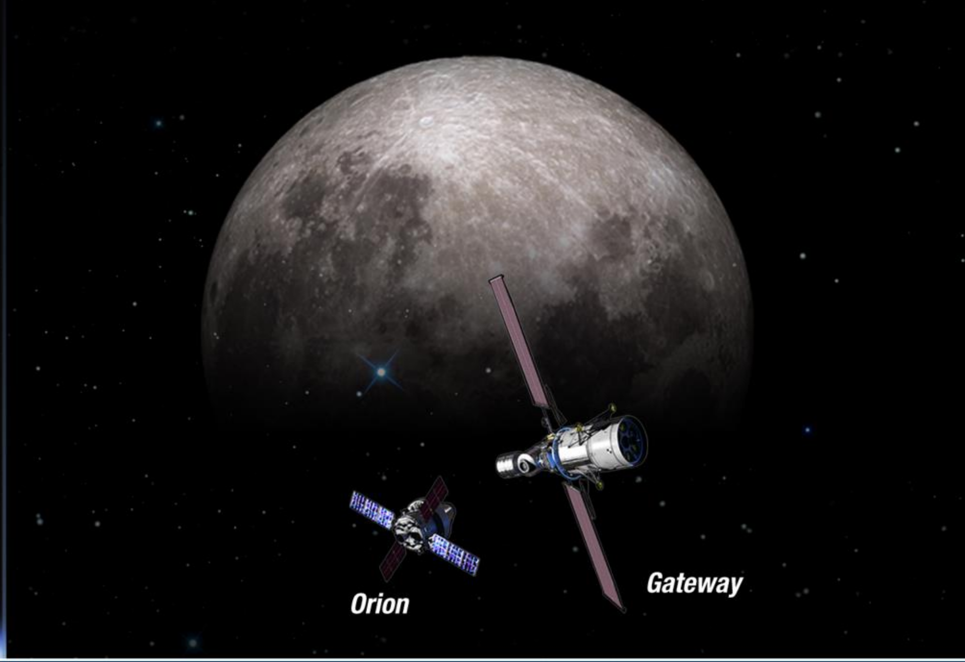

OmegA


Vulcan

The International Space Station

The Centerpiece of Exploration and Model for a New Future in Space





Continuous and ongoing cargo and crew operations aboard space station, along with commercial and international partnerships, allows human exploration to advance at a sustainable pace

CARGO **CREW**

Increment 61 Overview: Crew

Increment 61 began upon Soyuz 58S undock on 10/03/19

Andrew Morgan
FE (NASA)

Oleg Skripochka
(Roscosmos)

Luca Parmitano
(ESA)
ISS CDR Exp 61

Increment 61 concludes upon Soyuz 59S Undock on 2/6/20

Alexander Skvortsov
(Roscosmos)

Jessica Meir
(NASA)

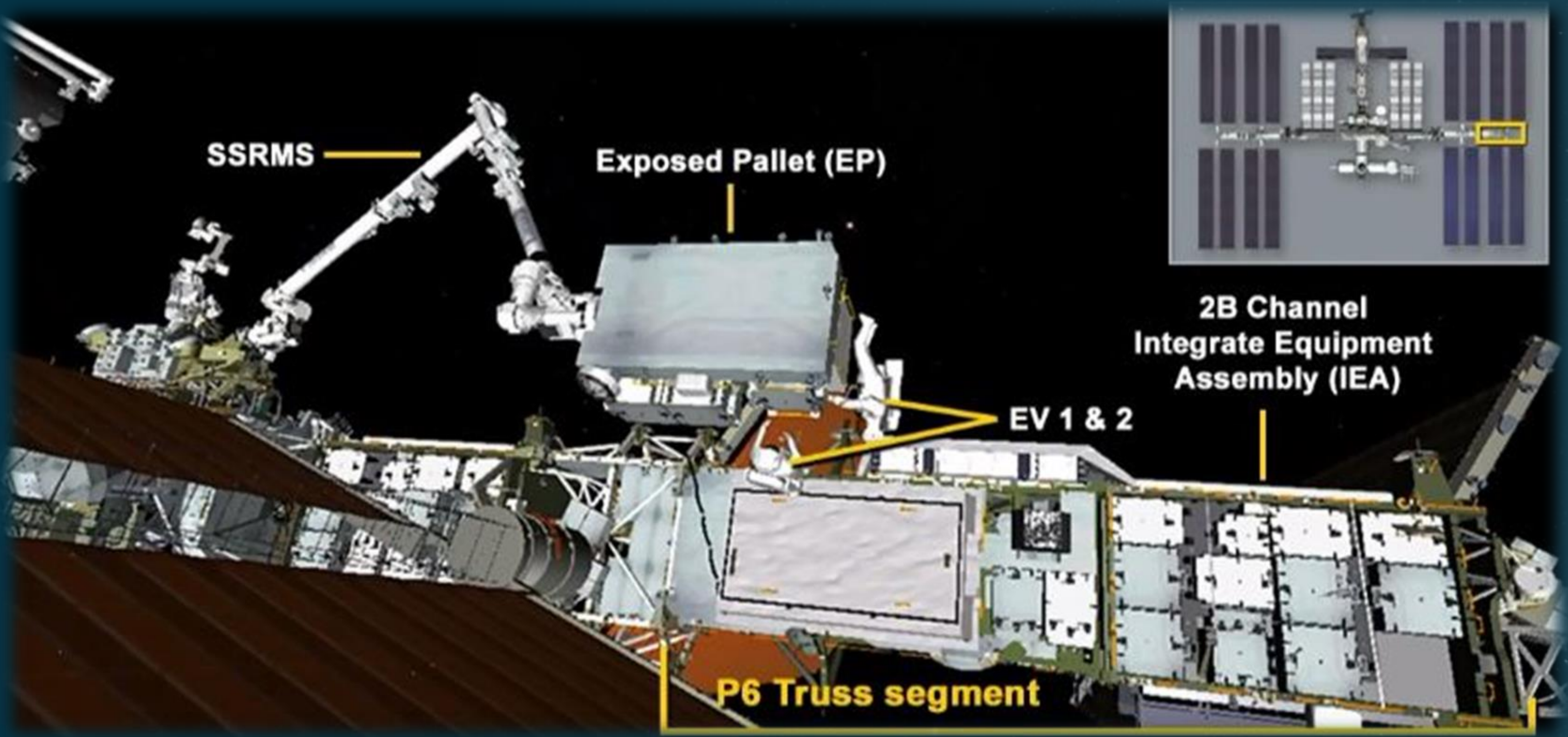
Christina Koch
(NASA)

Flight Plan – Increment 61

- 09/25/19 – Soyuz 61S Launch & Dock (NASA/Morgan, NASA/Meir, Roscosmos/Skripochka)
- 10/03/19 – Soyuz 58S Undocking (NASA/Hague, Roscosmos/Ovchinin, UAE/Almansoori)
- 10/06/19 – US EVA #56 (P6 Battery R&R)
- 10/11/19 – US EVA #57 (P6 Battery R&R)
- 10/18/19 – US EVA #58 (BCDU R&R)
- 11/01/19 – HTV-8 Release
- 11/02/19 – Northrop Grumman CRS-12 Launch (Capture/Berth on 11/04/19)
- Nov. ‘19 – AMS Repair Spacewalks (series of 4-5 EVAs)
- Dec. ‘19 – SpaceX CRS-19 Launch, Capture and Berth
- 12/17/19 – Boe-OFT Launch (Docking on 12/18/19)
- 12/20/19 – Progress 74P Launch (Docking on 12/22/19)
- Dec. ‘19 – SpaceX-Demo2 Launch and Docking
- Jan. ‘20 – SpaceX CRS-19 Release
- Jan. ‘20 – SpaceX-Demo2 Undock
- 02/06/19 – Soyuz 59S Undock (NASA/Koch, ESA/Parmitano, Roscosmos/Skvortsov)

EVA Summary – P6 Battery Upgrade / BCDU R&R

A series of five spacewalks was planned to replace 12 nickel-hydrogen (NiH2) batteries on power channels 2B and 4B of the P6 truss segment with six lithium-ion (Li-Ion) batteries and six battery adapter plates. The existing batteries will be upgraded with newer, more powerful batteries recently transported to the station and part of the overall upgrade of the station's power system that began with similar battery replacement during spacewalks in January 2017. The first two of these spacewalks was successfully completed in early October. However, the remaining three spacewalks are being rescheduled in order to first replace a Battery Charge / Discharge Unit (BCDU) that failed to activate following successful installation of the first set of Li-Ion batteries.



The new BCDU, hardware that regulates the amount of charge put into the batteries, was successfully replaced on October 18. This spacewalk also made history as the first all-woman spacewalk and was performed by NASA astronauts Christina Koch and Jessica Meir.

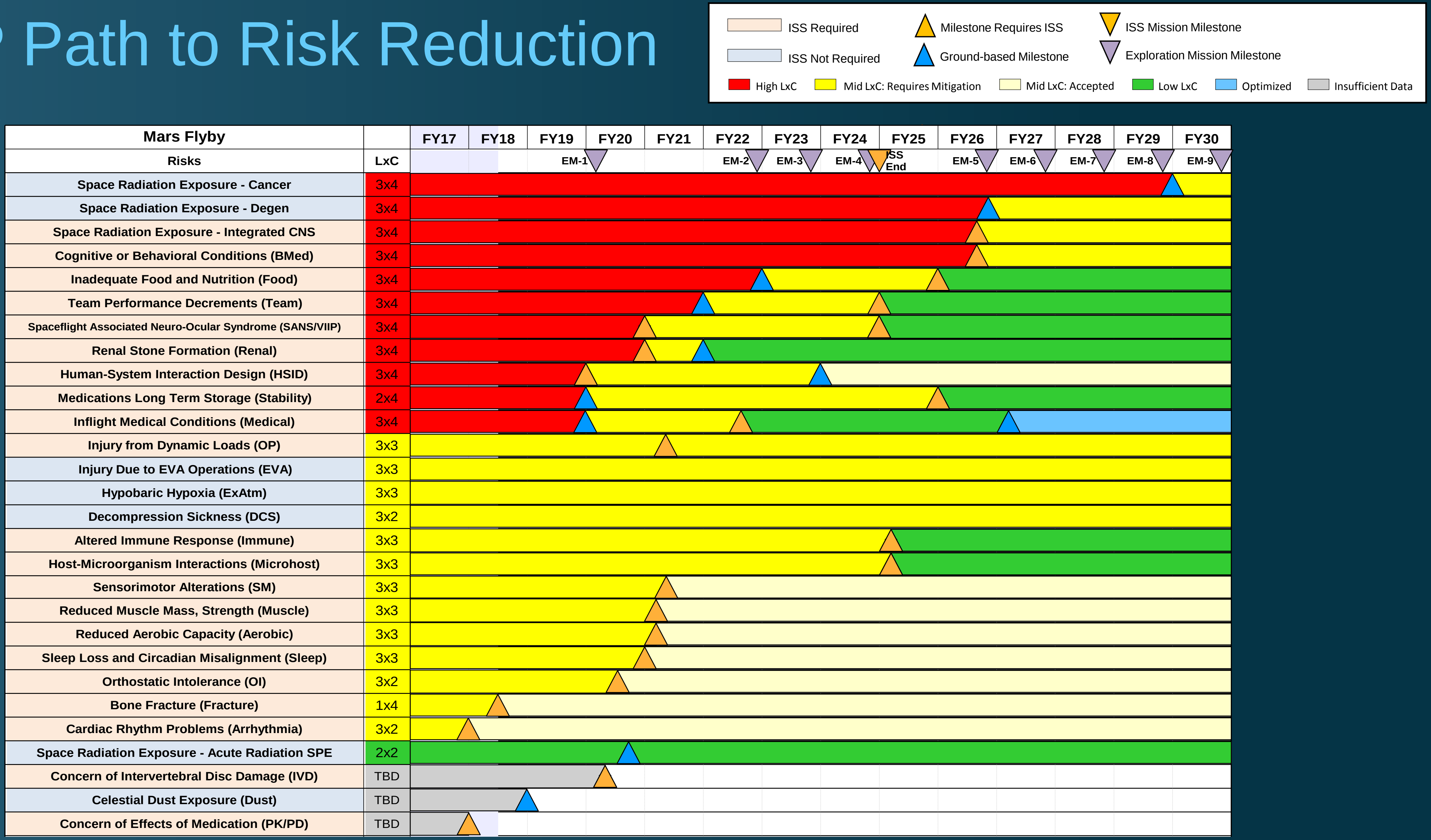
FY18-19 Agency Priority Goal

Use the International Space Station (ISS) as a testbed to demonstrate the critical systems necessary for long-duration missions. Between October 1, 2017, and September 30, 2019, NASA will initiate at least eight in-space demonstrations of technology critical to enable human exploration in deep space.

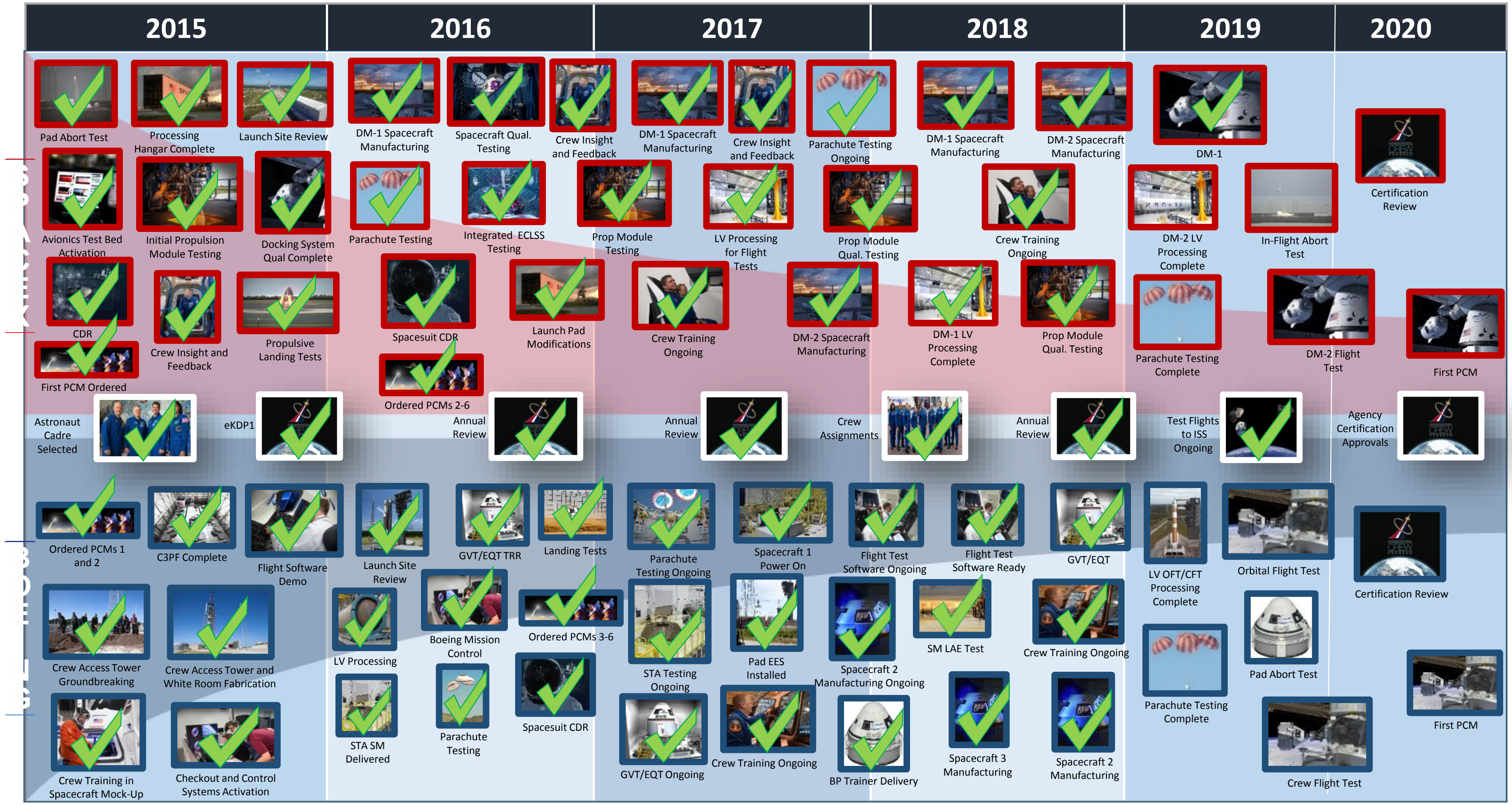
- **Goal focuses on Exploration-enabling demonstrations to be conducted on ISS**
- **Includes demonstrations funded by ISS, AES, HRP, Orion, and STMD**

FY18	FY19
1. Aerosol Sampler 2. Combination Acoustic Monitor	3. Refabricator 4. Hybrid Electronic Radiation Assessor (HERA) 5. Siloxane control technology (CHIPS filters) 6. Thermal Amine 7. Astrobee 8. RFID Enabled Autonomous Logistics Management (REALM)-2 9. SAM Major Constituents Analyzer

HRP Path to Risk Reduction



Commercial Crew to the International Space Station



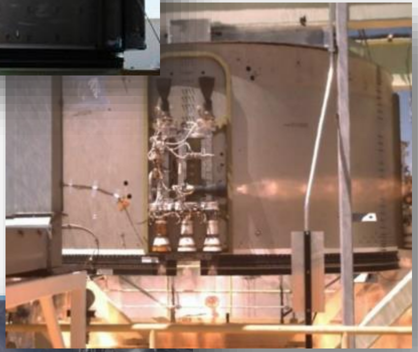
Last Updated
Oct 2019

Boeing Pad Abort Test Status

Pad Abort Test (PAT) Trending to Early November Launch Readiness - Target Date 11/4/19

- **Purpose is to validate end-to-end performance and functionality of the Launch Abort System**
- **Test Summary**
  - Mode Ia Abort from pad abort conditions
  - Test Location: White Sands Missile Range (WSMR)
  - Vehicle Configuration:
    - Spacecraft-1 CM and SM
    - ULA-delivered flight-like LVA including updated abort vent doors
  - CCP to support from WSMR and from MCC-H
- **Status**
  - PAT predicted performance delivered 7/31/19, showing margin against Commercial Crew Pad Abort requirement
    - NASA GNC IV&V shows good agreement with Boeing results
  - LVA abort vent door test successfully completed 8/15/19
  - CM/SM Mate Complete 9/18/19
  - SC1 CCV Power-up Complete 9/21/19
  - Set-Up for MMH Prop Loading 10/19/19
  - Test Readiness Review 10/28/19

Spacecraft being readied for PAT



Testing on Starliner's in-space maneuvering and launch abort systems

Boeing Orbital Flight Test Status

Orbital Flight Test (OFT) Trending to Mid-December Launch Readiness - Target Date 12/17/19

- **Spacecraft #3**
  - CM/SM mate complete 10/17/19
  - CM Integrated Avionics Acceptance testing complete
    - Boeing Integrated Propulsion Control R&R and regression testing complete
    - Prop regulator rebuild and retest complete
    - Final CM build and RF testing completed prior to CM/SM mate
  - Preparations for final CCV acceptance testing in work
  - Final close-outs in work
- **Atlas V (AV-080) OFT Launch Vehicle**
  - Booster, Centaur and Launch Vehicle Adapter (LVA) production complete
    - Centaur: Arrived at CCAFS on 10/18/18
    - LVA: Arrived at CCAFS on 11/12/18
    - Booster: Arrived at CCAFS on 12/6/18
  - AV-080 Booster horizontal processing complete – Ready to stack
  - AV-080 Centaur stacked and mated to LVA and ISA – Ready to mate to Booster
- **System Level-Subsystem Level Testing**
  - Structural Test Article (STA) testing completed
  - Environmental Qualification Testing (EQT) completed
  - Parachute System Qualification Testing (PSQT) 5/5 completed
  - Service Module Hotfire 2.0 Testing completed
    - Low Altitude Abort and Nominal Mission sequences
  - Parachute Compartment Reliability Testing underway (3/6 completed)
    - Remaining 3 tests planned throughout the fall
- **OFT Joint Tests and Analysis with ISS Remaining**
  - JA 9 Clearance During Docking/Mated Ops (SC# 3) Final As-Built compare NET 10/28/19
  - JT 10 Crew Equipment Interface Test (CEIT) (SC #3)
  - JT 11 Microbial and Fungal Sampling (SC #3)
  - JT 12 Closed Hatch Off Gassing (SC #3)

Spacecraft #3 in final prep

Atlas V Booster AV-080

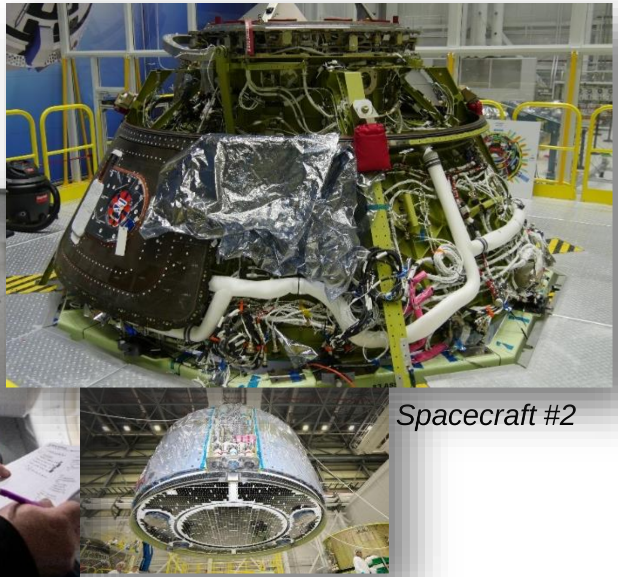
Boeing Crew Flight Test Status

Crew Flight Test (CFT) Trending to Early 2020 Launch Readiness

- **Spacecraft #2 - CM/SM Basic Build In-work**

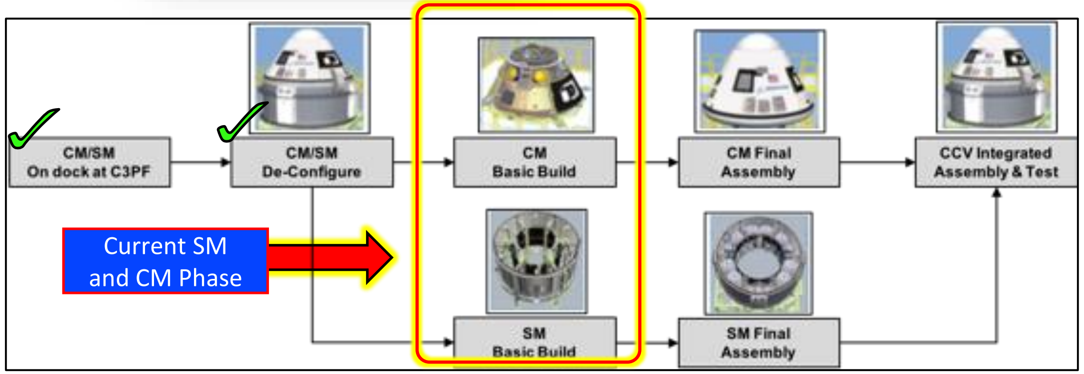
  Completed
  - Upper dome/lower dome mated 10/22/2019
  - Docking System Latch Actuator Installation
  - Atmosphere Revitalization System (ARS) component assembly build-up
  - NAFION assembly and installation
  - Removal of Orbital Maneuvering And Control (OMAC) Isolation Valves
  - Active Thermal Control System (ATCS) Check valve test
  - Flexhose precision cleaning
  - Crew suited training activities ongoing

  Remaining
  - Harness High Potential and Continuity Tests
  - LRS Panel buildup
  - PCS Panel buildup
  - Command Valve Panel rework
  - ATCS assembly/bellows rework
  - Doghouse reaction control system isolation valve inspection
  - Three way valve installation
  - OMAC bracket modification
- **Atlas V (AV-082) Launch Vehicle**
  - Booster
    - Production complete
    - Arrived CCAFS on 6/1/19
  - Centaur
    - Production complete
    - Arrived CCAFS on 6/1/19
  - Launch Vehicle Adapter
    - In work on remaining Aeroskirt/Truss manufacturing and assembly activities
    - Prep for shipment to CCAFS fall/winter 2019



Spacecraft #2

CFT suited crew training



Dragon Static Fire Anomaly Investigation

SpaceX encountered an anomaly during attempted static fire testing of the SuperDraco propulsion system on 4/20/19 resulting in the loss of the vehicle

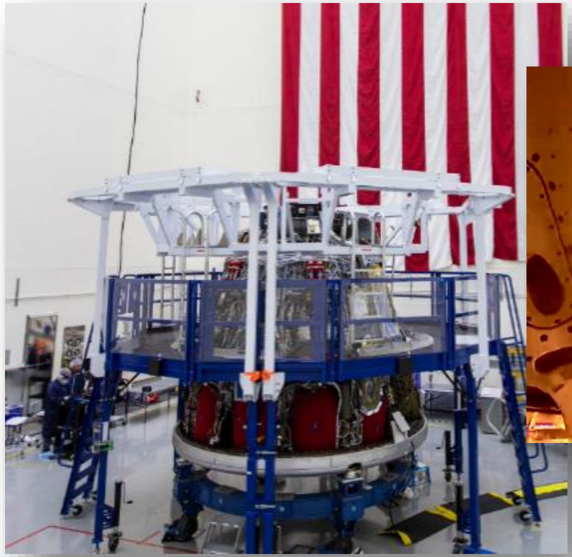
- **A formal investigation was begun, which included NASA participation**
- **Fault tree disposition is nearly complete**
- **The SpaceX static fire anomaly investigation team briefed NASA leadership on progress 8/15/19**
- **Anomaly associated corrective actions and design changes were identified and already being implemented by SpaceX**
- **Prior to the IFAT Anomaly SpaceX was already planning to make a few changes between DM-1 and DM-2**
  - Design changes on the low-flow side of the propulsion system were approved on 6/20/19
  - Changes on the high-flow side of the system are finalized, with ground-testing nearly complete
  - Hardware modifications installed August/September
  - Static Fire and IFAT capsule shipped to KSC on 9/25/19
  - Static Fire Test Readiness Review conducted on 10/21/19 with a delta TRR on 10/26 to discuss prop module testing
  - Static fire test NET 11/2/19
- **NASA plans to ensure that the necessary hazards and controls resulting from all changes get incorporated into the prop system hazard reports prior to approving them for Phase III (DM-2)**
  - Team is coordinating verification evidence product impacts and constraints with the respective requirement owners

DM-1 Dragon on test-stand prior to anomaly

SpaceX In-Flight Abort Vehicle Status

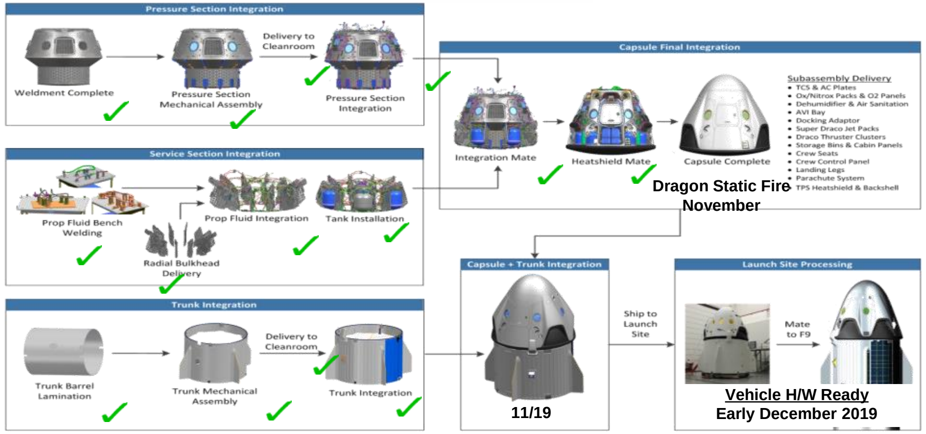
In-Flight Abort Test (IFAT) Trending to Early December Launch Readiness - Targeted after CRS 19

- **Focus on integration of the updated propulsion system and pressure system integration**
- **Test Summary**
  - Launch from LC-39A at KSC
  - S1B escape mode initiated at ~88s MET
  - Test article consists of:
    - F9 Block 5 4th flight booster and interstage
    - F9 Block 5 2nd stage with MVacD simulator (no engine)
    - Stage extension, trunk, and Dragon Capsule 205 incorporating SuperDraco propulsion system updates since static fire anomaly
  - IFAT F9 Static Fire and IFAT will be dry-runs for Demo 2+ ops support teams including exercising crew timeline
- **Status**
  - IFAT trunk shipped to CCAFS 8/16/19
  - IFAT Capsule shipped to CCAFS 9/27/19
    - Open installation work transferred to CCAFS (final harnessing, pod panels, nosecone)
  - 1st stage refurbishment completed in Hawthorne shipped to CCAFS 9/22/19
  - 2nd stage proof/tanking testing complete, awaiting shipment to CCAFS
  - Re-baseline NASA/SpaceX IFAT TIM conducted 9/25/19



IFAT spacecraft

Testing the upgraded launch escape system



SpaceX Demo-2 Vehicle Status

Demo-2 Currently Trending to First Quarter 2020 Launch Readiness

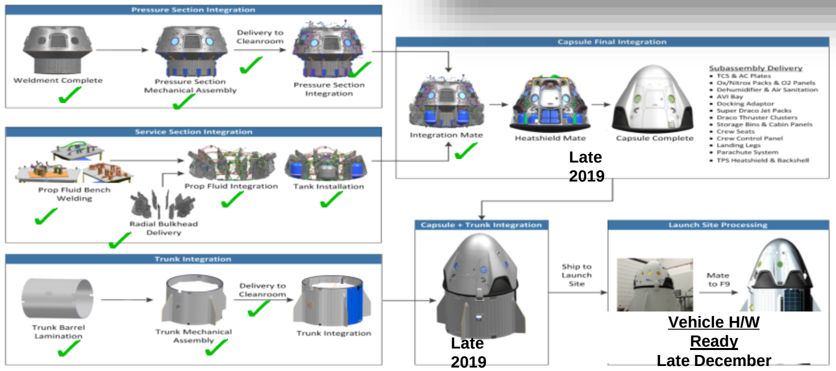
- **Dragon Spacecraft**
  - Docking Adapter installed
  - SuperDraco ATP complete
  - Trunk structure is complete
  - Avionics and system checkouts in-work to test integrated systems
  - Heat Shield build is complete
  - Expected to ship to KSC in early December

- **Falcon 9 Launch Vehicle**
  - 1st Stage shipped to McGregor and stage testing completed
  - Static fire test 8/29/19
  - Decision reached regarding MVacD upper stage engine configuration
    - Upper stage shipment to McGregor in October/November
    - Upper stage testing in November and ship to CCAFS in time for launch readiness review

- **Spacesuit production of primary suits nearing completion**
  - Backup suit production in work

Administrator Jim Bridenstine and Elon Musk with DM-2 spacecraft and spacesuits

DM-2 suited crew training



Why go to The Moon?

Proves technologies and capabilities for sending humans to Mars

Establishes American leadership and strategic presence

Inspires a new generation and encourages careers in STEM

Leads civilization changing science and technology

Expands the U.S. global economic impact

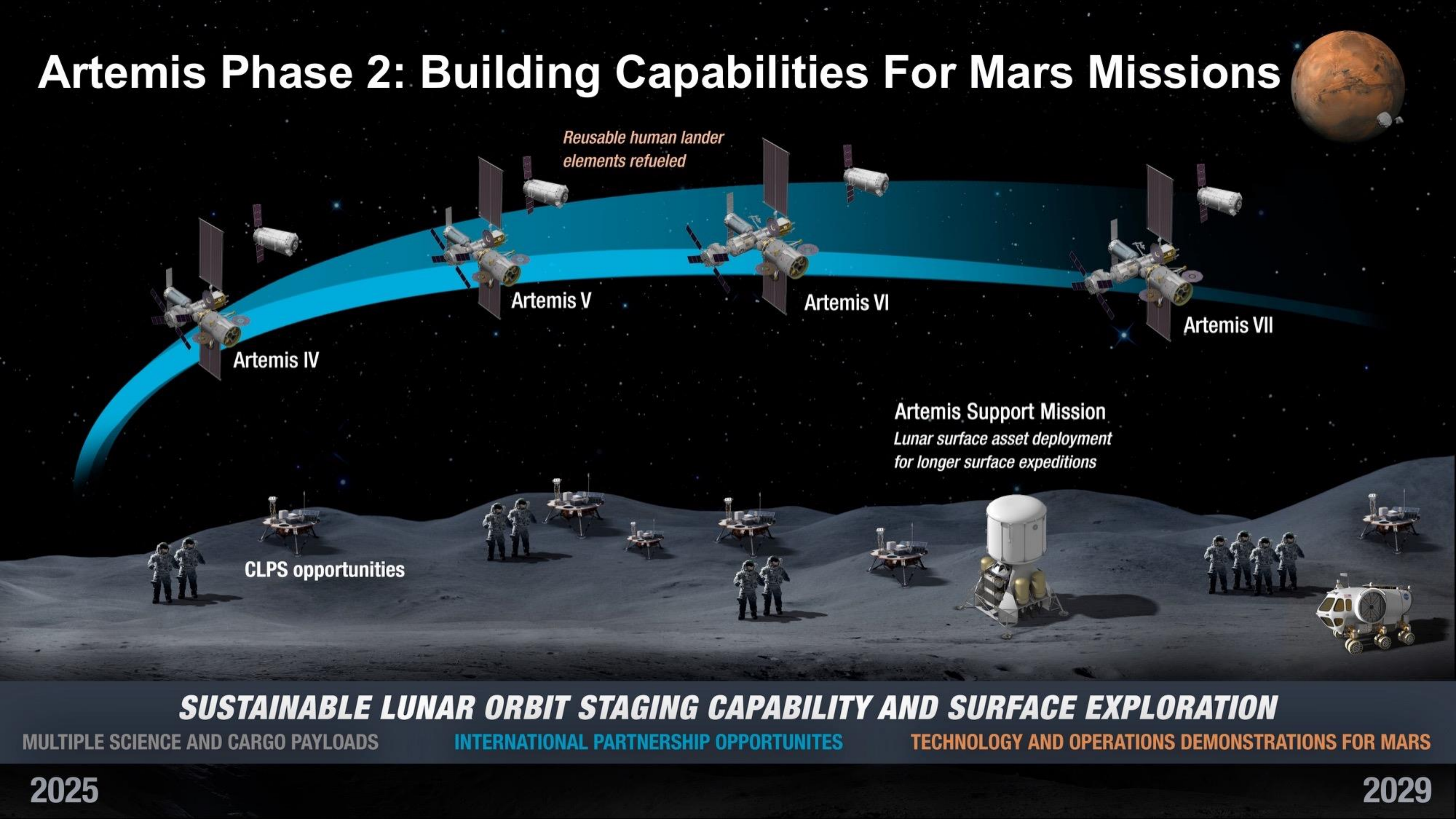
Broadens U.S. industry and international partnerships in deep space

Moon Before Mars

On the Moon, we can take reasonable risks while astronauts are just three days away from home.

There we will prove technologies and mature systems necessary to live and work on another world before embarking on what could be a 2-3 year mission to Mars.

Artemis Phase 2: Building Capabilities For Mars Missions



Lunar Science by 2024

Polar Landers and Rovers

- First direct measurement of polar volatiles, improving understanding of lateral and vertical distribution, physical state, and chemical composition
- Provide geology of the South-Pole Aitken basin, largest impact in the solar system

Non-Polar Landers and Rovers

- Explore scientifically valuable terrains not investigated by Apollo, including landing at a lunar swirl and making first surface magnetic measurement
- Using PI-led instruments to generate Discovery-class science, like establishing a geophysical network and visiting a lunar volcanic region to understand volcanic evolution

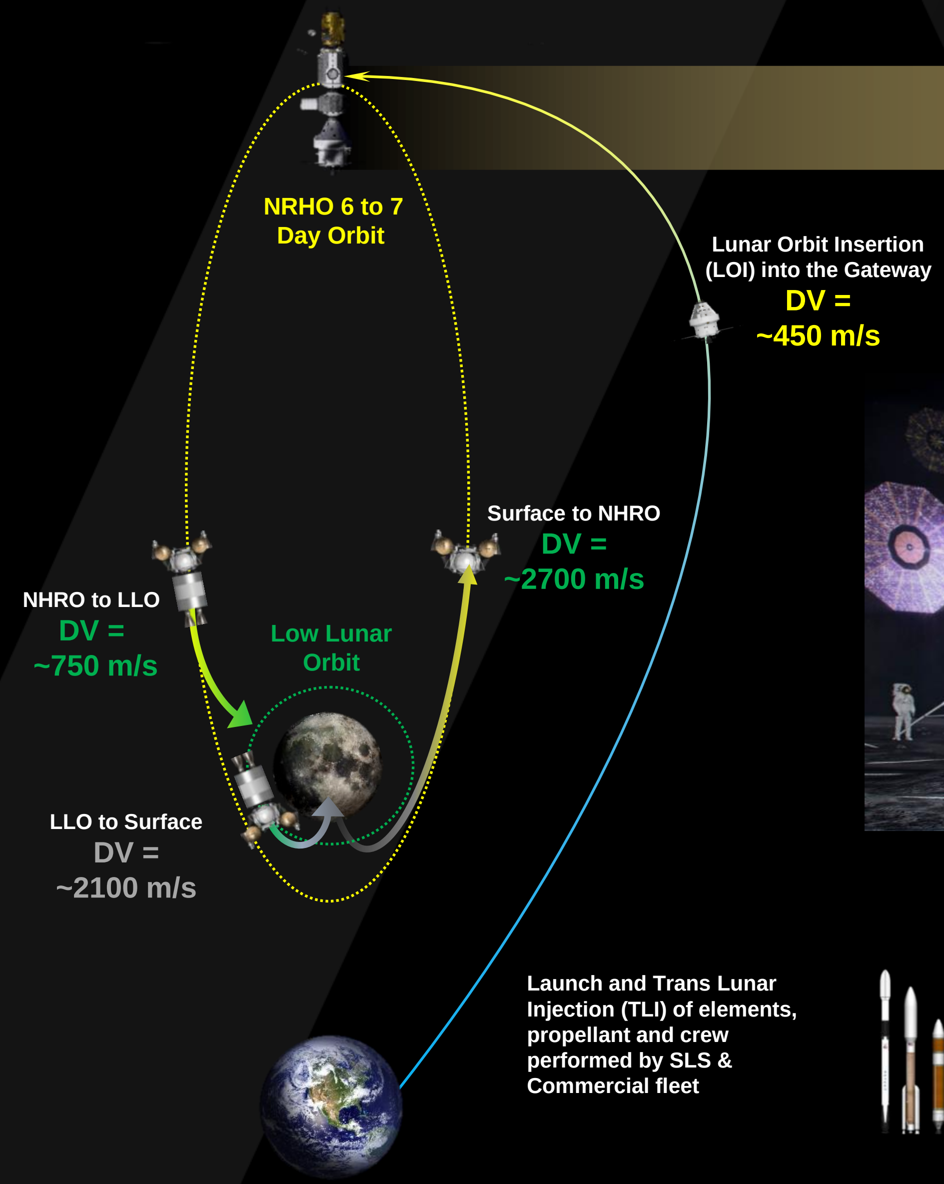
Orbital Data

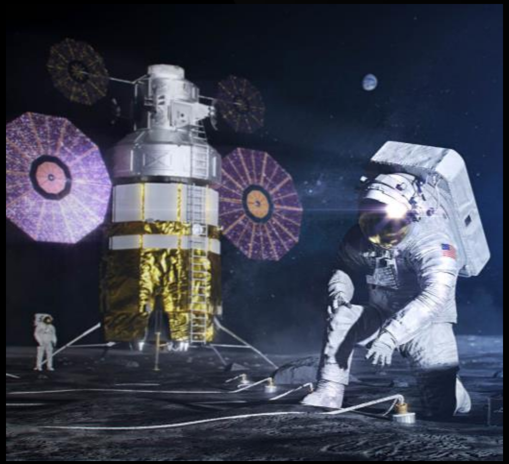
- Deploy multiple CubeSats with Artemis 1
- Potential to acquire new scientifically valuable datasets through CubeSats delivered by CLPS providers or comm/relay spacecraft
- Global mineral mapping, including resource identification, global elemental maps, and improved volatile mapping

In-Situ Resource Initial Research

- Answering questions on composition and ability to use lunar ice for sustainment and fuel

The Physics Driving Lunar Architecture Choices





Crewed lunar surface missions to polar regions require 6,390 m/s roundtrip through Gateway.

ΔV for equivalent Direct to LLO mission is approximately 5% lower but requires slightly more mass for first mission. However, for subsequent missions, the Gateway approach significantly reduces mass and cost

Gateway approach allows for ΔV to be distributed across multiple elements reducing mass per launch

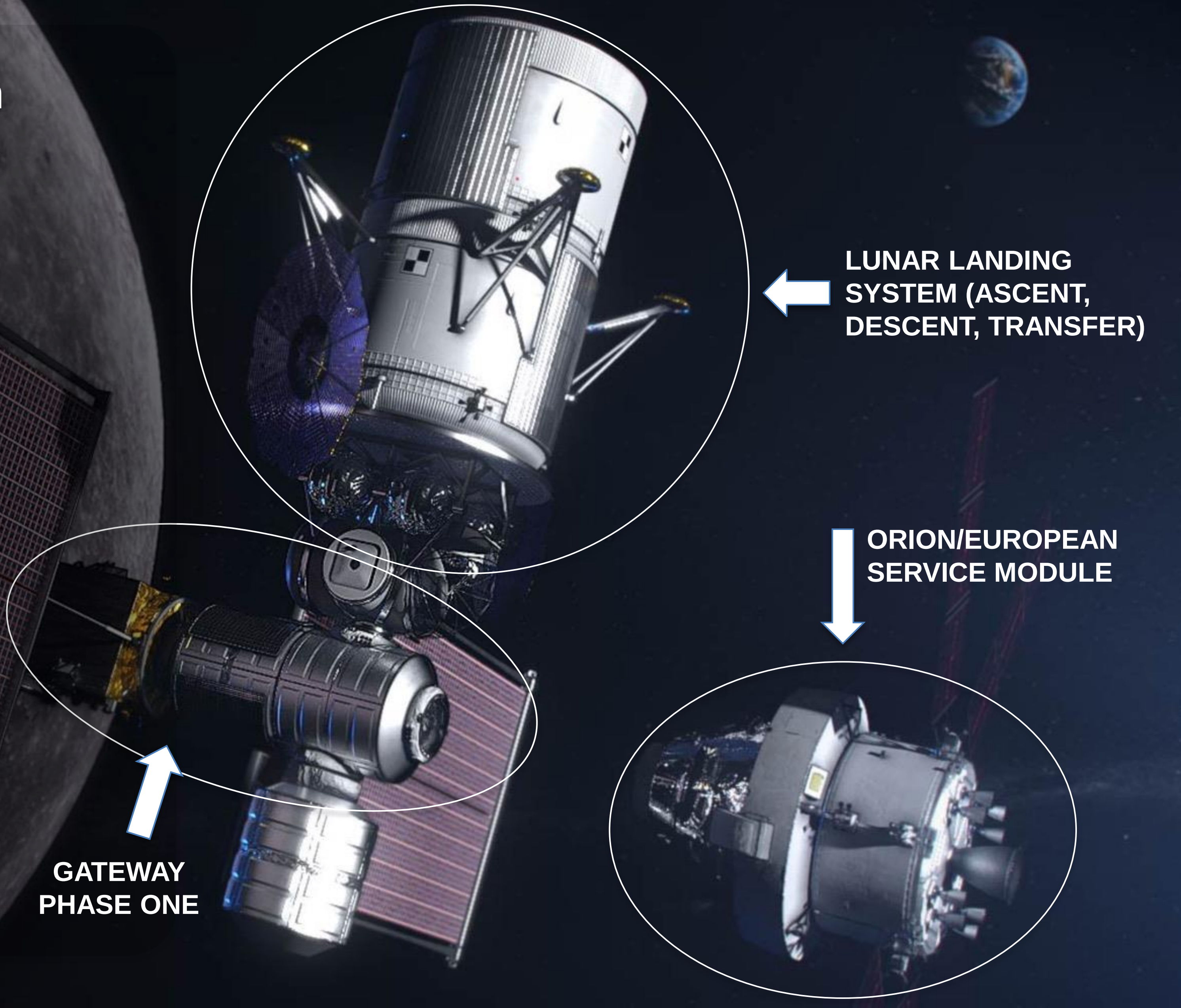
Commercial Launch Vehicles projected to be capable of sending up to 15 mT to TLI (using upper stage for TLI burns and service module or integrated propulsion for NRHO insertion burn).

SLS projected to be capable of sending 10 mT (Block 1B, co-manifested with Orion) to 40 mT (Block 1B cargo) to TLI.

Near-Rectilinear Halo Orbit

Gateway Enables Exploration of the Moon and Mars

- Initial Gateway focuses on the minimum systems required to support a 2024 human lunar landing while also supporting Phase 2
- Provides command center and aggregation point for 2024 human landing
- Establishes strategic presence around the Moon – US in the leadership role
- Creates resilience and robustness in the lunar architecture
- Open architecture and interoperability standards provides building blocks for partnerships and future expansion



Power and Propulsion Element

MAXAR

- **Power** – 60 kW+ provided by Roll Out Solar Array (ROSA) and Maxar’s 1300 commercial power subsystem
- **Propulsion** – Leverage NASA development of 12.5 kW Electric Propulsion (EP), and internal Maxar advanced EP development, with Maxar expertise in system accommodation of EP elements
- **Communications** – Ka-band, X-band
- **Guidance Navigation and Control**
- **Gateway Interface Support** –docked components, visiting vehicles, robotics, science payloads, Human Landing System
- **Payload Transfer** – 1000kg for lunar lander or science instruments

Gateway HALO

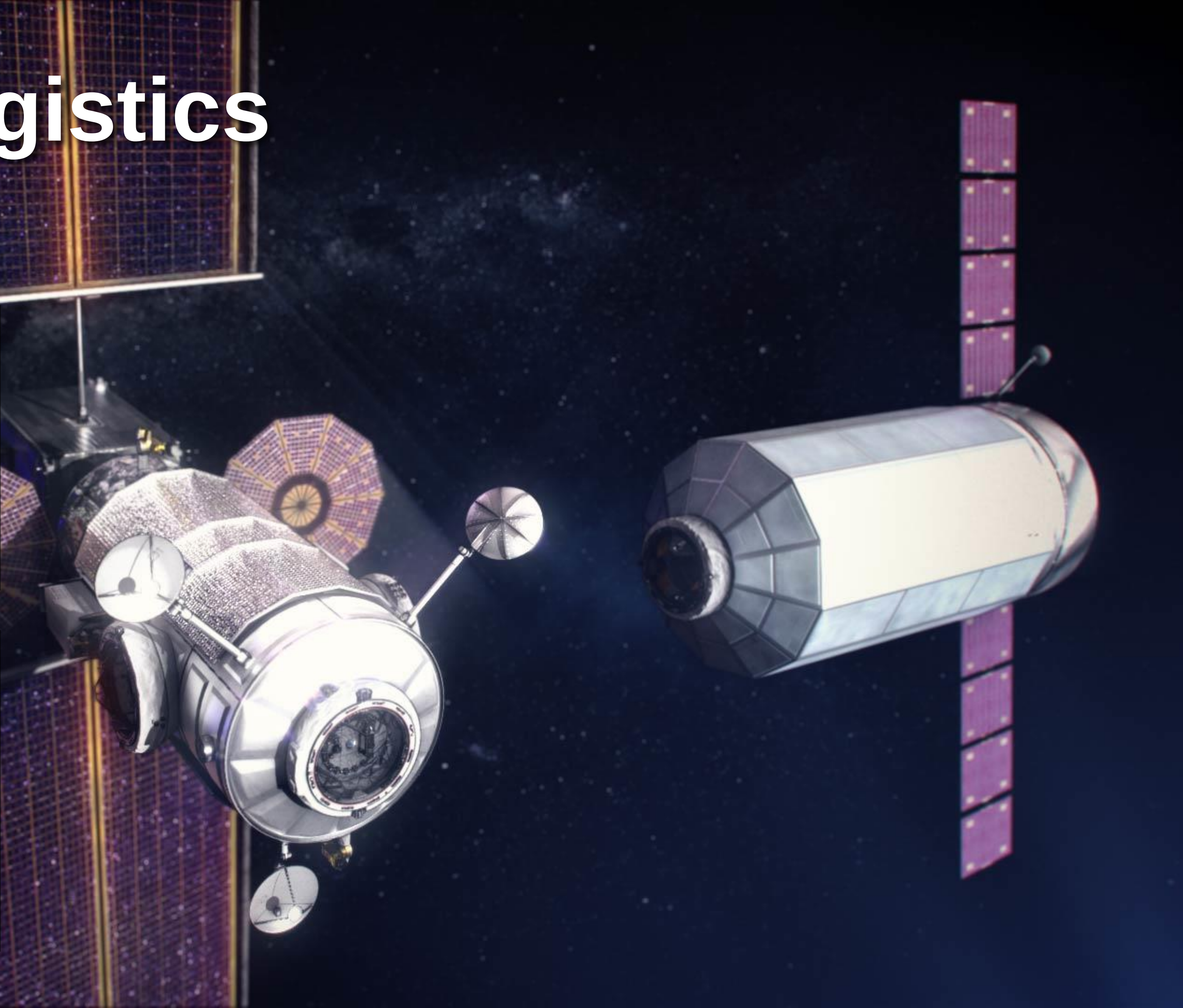
(Habitation and Logistics Outpost)

- RFP issued to Northrop Grumman
- Minimum capability necessary to support a lunar mission, with significant reliance on Orion life support and crew systems

Gateway Logistics Services

U.S. industry to begin delivering cargo, experiments, and supplies to deep space beginning in 2024.

- **June 14** – Draft RFP issued to U.S. industry
- **June 26** – Industry forum with media availability
- **Aug 16** – final solicitation for firm fixed-price contract; proposals received Oct. 16



Human Landing System

NextSTEP Appendix H: Human Landing System

- Synopsis Issued: April 8, for **Ascent Element**
- Synopsis updated: April 26, for **development, integration, and crewed demonstration of integrated landing system**
- Draft solicitation: July 19
- Second draft solicitation: Aug 30
- Final solicitation: Sept 30
- Proposals due: Nov. 1

Risk reduction studies and prototypes contracted separately under Appendix E in March 2019 are ongoing

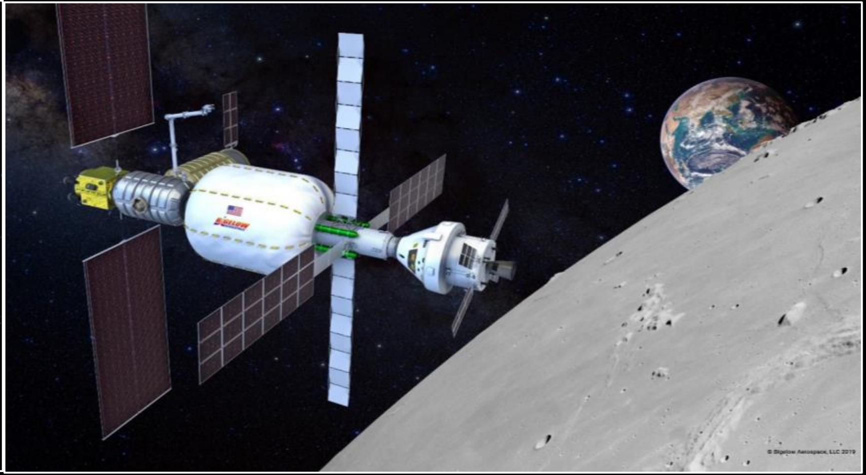
Surface Suit

Exploration Extravehicular Mobility Unit (xEMU)

- In-house build for 2024 expedition
- Testing component and full suit on ISS through 2023
- RFI issued Oct. 4 seeking industry input on transitioning production line to private sector for 2025 and beyond

NextSTEP Habitat Prototype Testing

Five full-sized ground prototypes delivered for testing in 2019.



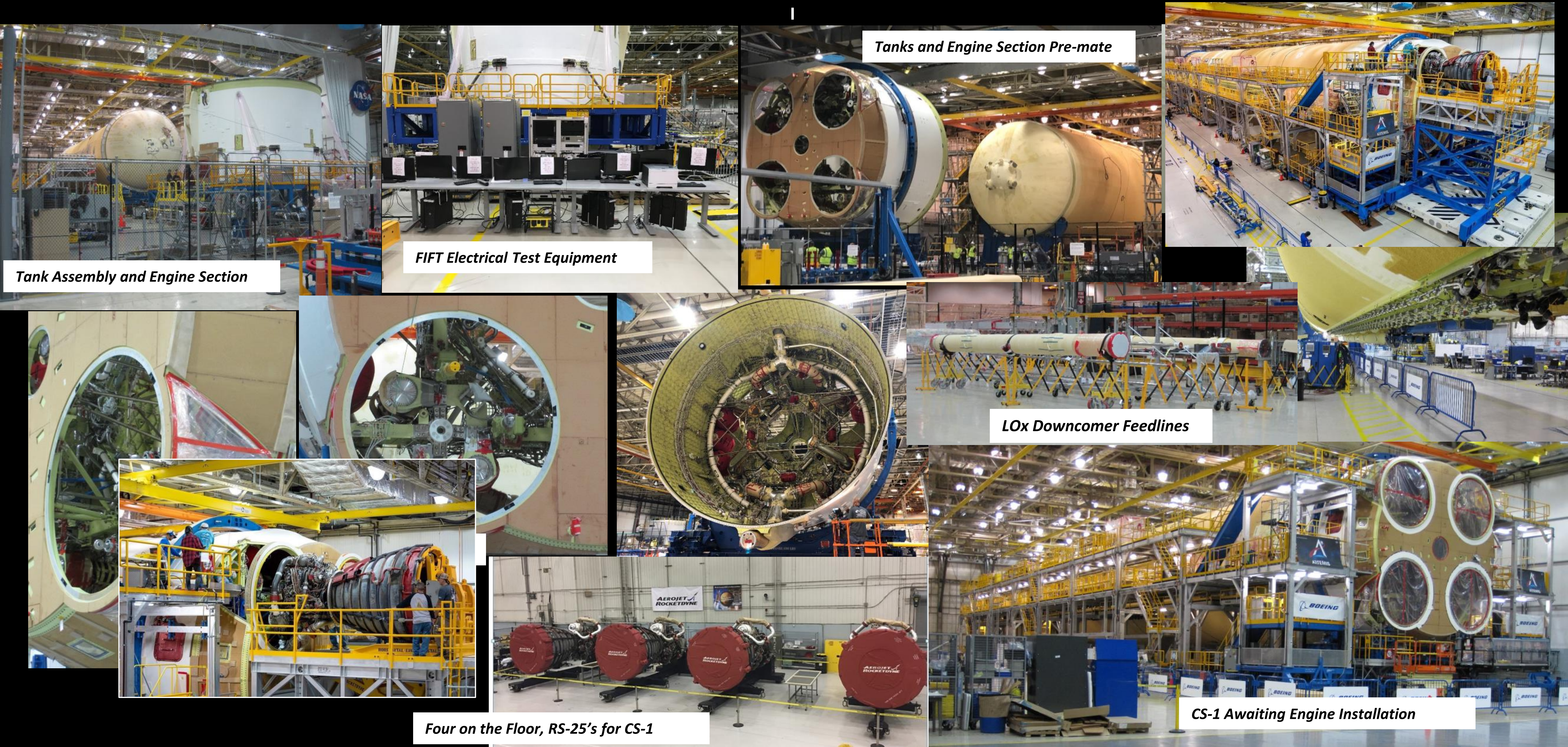
"Because of this prototyping exercise, we are 12-18 months farther along than we would normally be at this stage of concept development. Future programs should go through this approach along with requirements iteration with NASA."

"The NextSTEP approach has been really helpful. The mockup showed us we had more cargo space in our habitat than we originally believed based on the CAD models."

SLS SUMMARY

- SLS is America's rocket
  - Building block design approach enables capability to achieve near term objectives and accomplish NASA's vision for future exploration including Mars
- SLS's progress over last 18 months has demonstrated confidence in support for NASA's plans
  - Artemis I build approaching completion; Green Run will demonstrate the liquid propulsion system
  - Artemis II build progressing; production timelines grounded in build data
  - RS-25 engines production restarted to support SLS planning milestones
- SLS is aggressively planning for missions beyond Artemis I
  - Procurement actions in work to enable long lead procurement
  - Manifest definition and mission requirements, supported by funding, needed to enable lunar landing in 2024 and missions beyond 2024

CORE STAGE 1 PRODUCTION STATUS AT MAF



Tank Assembly and Engine Section

FIFT Electrical Test Equipment

Tanks and Engine Section Pre-mate

LOx Downcomer Feedlines

Four on the Floor, RS-25's for CS-1

CS-1 Awaiting Engine Installation

SLS EXECUTIVE SUMMARY

- SLS delivers unique capabilities for space exploration

- SLS experienced significant challenges with program startup and first build
  - Learning curve associated with business model and new design and new contractors
  - Flat funding not optimal for new development programs

- Program maturation over the last 18 months provides confidence in ability to support NASA's plans
  - Program planning and assumptions grounded by build data
  - Lessons learned yielding efficiencies, e.g. organizational realignment, labor hours, quantity of hardware discrepancies

- Procurement actions and manifest / mission definition required to actively mitigate program and enterprise risks

SLS HARDWARE - ENABLING MOON 2024 AND BEYOND

- Procurement actions are underway to enable the Moon 2024 mission
- Near-Term Funding is needed to support the baseline

Element	Artemis I (B1 Uncrewed)	Artemis II (B1 Crewed)	Artemis III (B1 Crewed)	SM-1 (B1 Cargo) *Alternate Mission*	Artemis IV (B1B Crewed)	Artemis V (B1B Crewed)	Artemis VI (B1B Crewed)	Artemis VII (B1B Cargo)	Artemis VIII (B2 Crewed)
Booster	✓	✓	✓		O	O	O	O	N/A
• BOLE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	O
Engines • RS25	✓	✓	✓		✓	O	O	O	O
• RL10	N/A	✓	✓		✓				
SPIE • LVSA	✓	O	O		N/A	N/A	N/A	N/A	N/A
• ICPS	✓	O	O		N/A	N/A	N/A	N/A	N/A
• USA	N/A	N/A	N/A	N/A	✓	✓ *	✓ *	✓ *	✓ *
• Fairing and PAF	N/A	N/A	N/A	O	N/A	N/A	N/A		N/A
Stages • Core	O	O	O		O	O	O	O	O
• EUS	N/A	N/A	N/A	N/A	O	O	O	O	O

✓ = Completed procurement actions ✓* = Completed procurement actions with options O = Open procurement actions

FOUNDATION FOR A GENERATION OF DEEP SPACE EXPLORATION

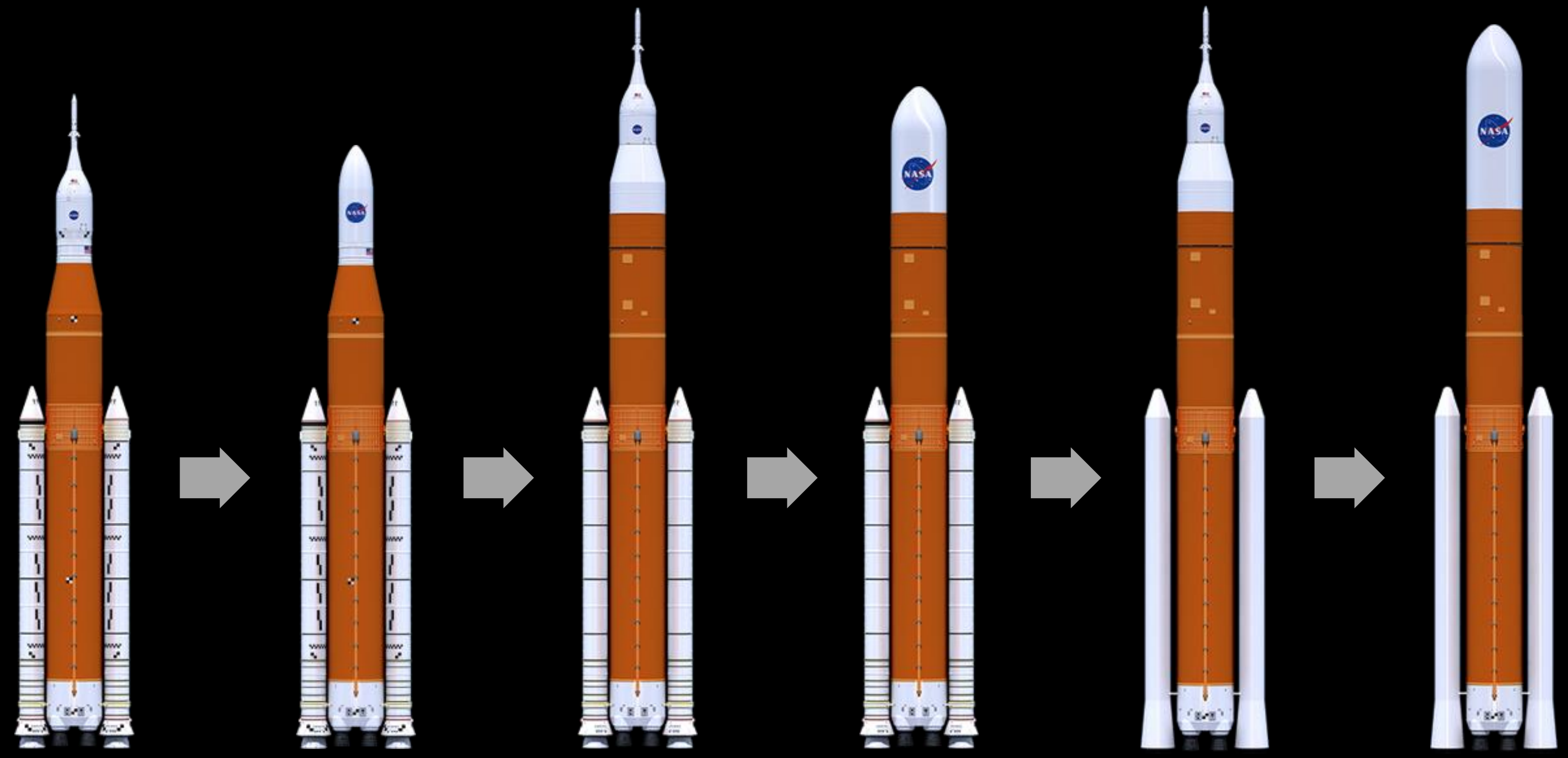
	SLS Block 1 Crew	SLS Block 1 Cargo	SLS Block 1B Crew	SLS Block 1B Cargo	SLS Block 2 Crew	SLS Block 2 Cargo
Payload to LEO	95 t (209k lbs)	95 t (209k lbs)	105 t (231k lbs)	105 t (231k lbs)	130 t (287k lbs)	130 t (287k lbs)
Payload to TLI/Moon	> 26 t (57k lbs)	> 26 t (57k lbs)	34–37 t (74k–81k lbs)	37–40 t (81k–88k lbs)	> 45 t (99k lbs)	> 45 t (99k lbs)
Payload Volume	N/A**	9,030 ft³ (256m³)	10,100 ft³ (286m³)**	18,970 ft³ (537 m³)	10,100 ft³ (286m³)**	34,910 ft³ (988 m³)
Maximum Thrust	8.8M lbs	8.8M lbs	8.8M lbs	8.8M lbs	11.9M lbs	11.9M lbs

Low Earth Orbit (LEO) represents a typical 200 km circular orbit at 28.5 degrees inclination

Trans-Lunar Injection (TLI) is a propulsive maneuver used to set a spacecraft on a trajectory that will cause it to arrive at the Moon. A spacecraft performs **TLI** to begin a lunar transfer from a low circular parking orbit around Earth.

The numbers depicted here indicate the mass capability at the Trans-Lunar Injection point.

** Not including Orion/Service Module volume

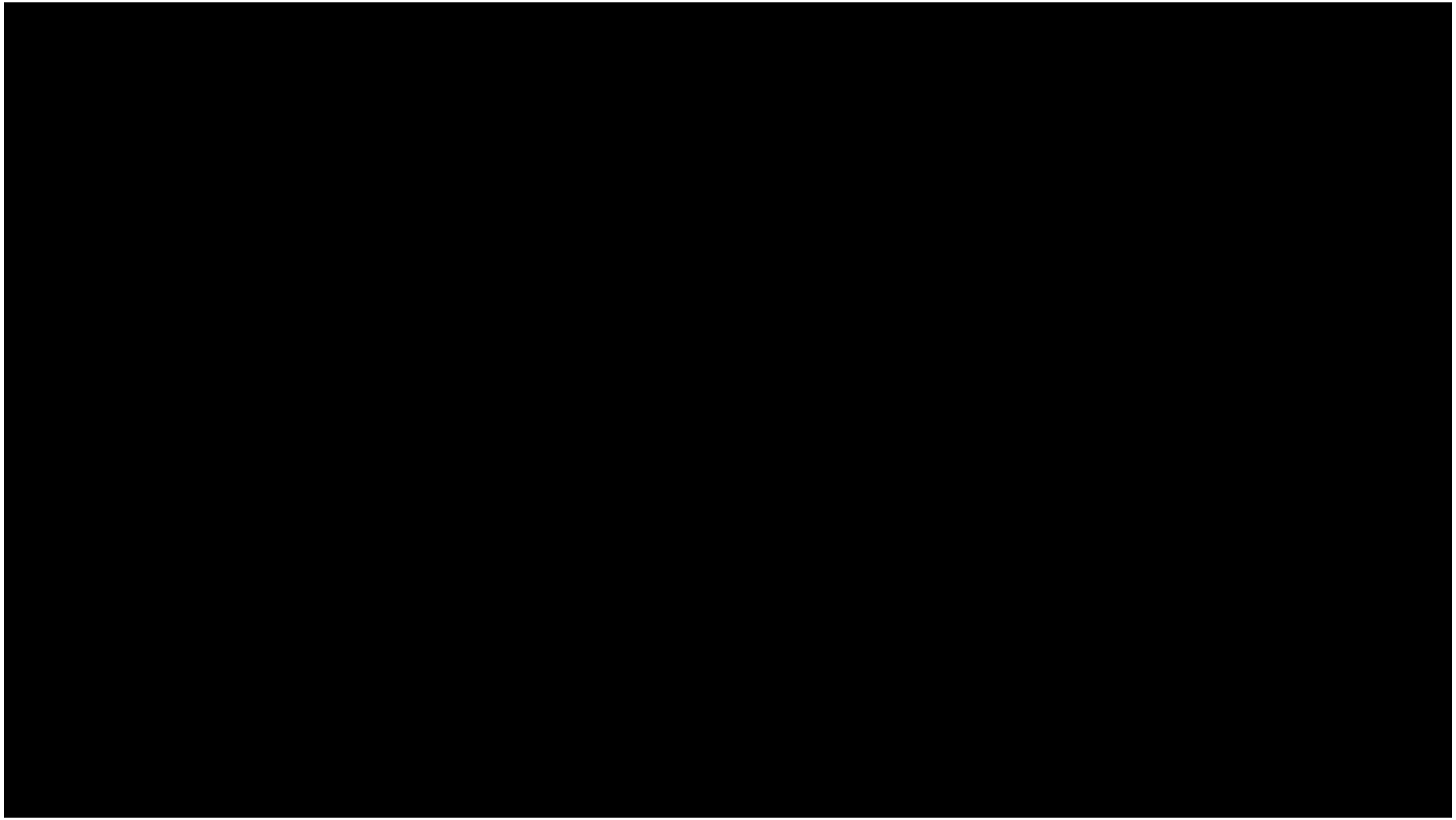


SSC’s B-2 Test Facility: A Brief Resume

- **Construction:** July 1963 through November 1966
- **Apollo Program:** Saturn V S-IC Stage Green Run Testing - December 1966 through October 1970
  - S-IC-T (Battleship) Testing for Facility Certification: December 1966 through March 1967
  - Flight Stage Green Run Testing (S-IC-4 through S-IC-15): April 1967 through October 1970
    => Apollo Missions 9-17, Skylab, and Static Displays at JSC and Infinity Science Center
- **Shuttle Program:** Main Propulsion Test Article (MPTA) Testing – December 1977 through January 1981
- **Out of Service:** 1981 through December 1998
- **X-Vehicle Program:** Low Cost Technology “Fastrac” Engine Testing for X-34 – January 1999 through October 1999
- **EELV/Commercial Space:** Delta IV Common Booster Core Testing – November 1999 through May 2001
- **Out of Service:** June 2001 through January 2012

Since 2012, SSC has led the refurbishment and build out of the B-2 test stand to support the SLS Core Stage Test

SSC B-2: Six Years of Nonstop Work



https://youtu.be/94ryD3b8qEE

Green Run Test Summary

- Green Run is a series of tests culminating in the Core Stage Hot-fire Test:
  - 1. Suspended Modal Test performed with the CS suspended vertically from the Stand crane
  - 2. Vehicle Avionics Power Turn-on and Checkout
  - 3. Safing Checks for Wet Dress Rehearsal (WDR)
  - 4. MPS & Engine Leak and Functional Checks
  - 5. Core Stage Engines and TVC System Hydraulic Checks
  - 6. Simulated Countdown
  - 7. Wet Dress Rehearsal (WDR) Test (i.e., Fill and Drain Test)
  - 8. Hot-Fire Test

  - Post Hot-Fire Refurbishment
  - Post Green Run Final Health & Status testing prior to shipment to KSC
  - Demate, lift and remove from Test Stand, ship to KSC

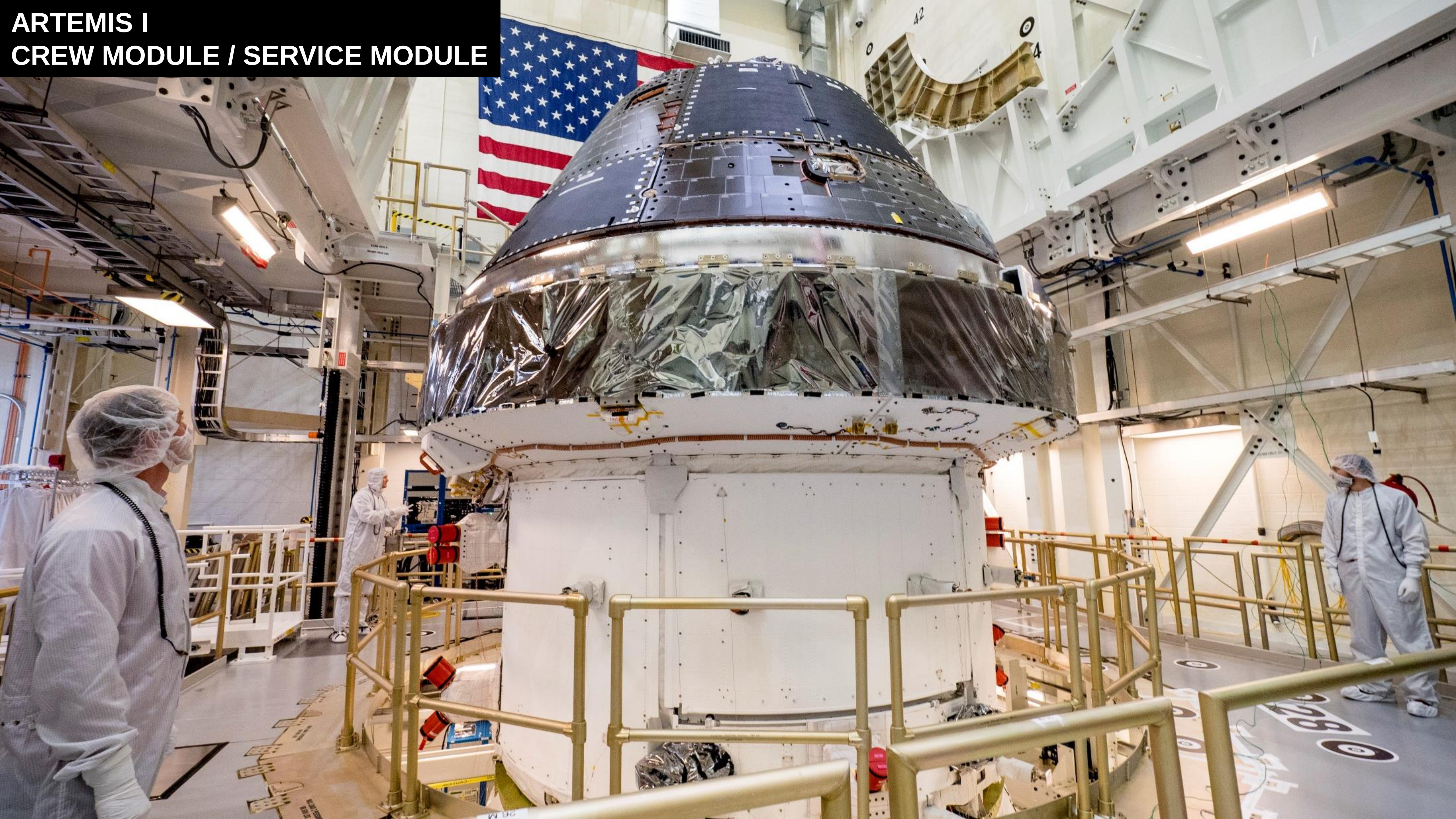
Core Stage in B-2 Stand

Green Run Test Objectives

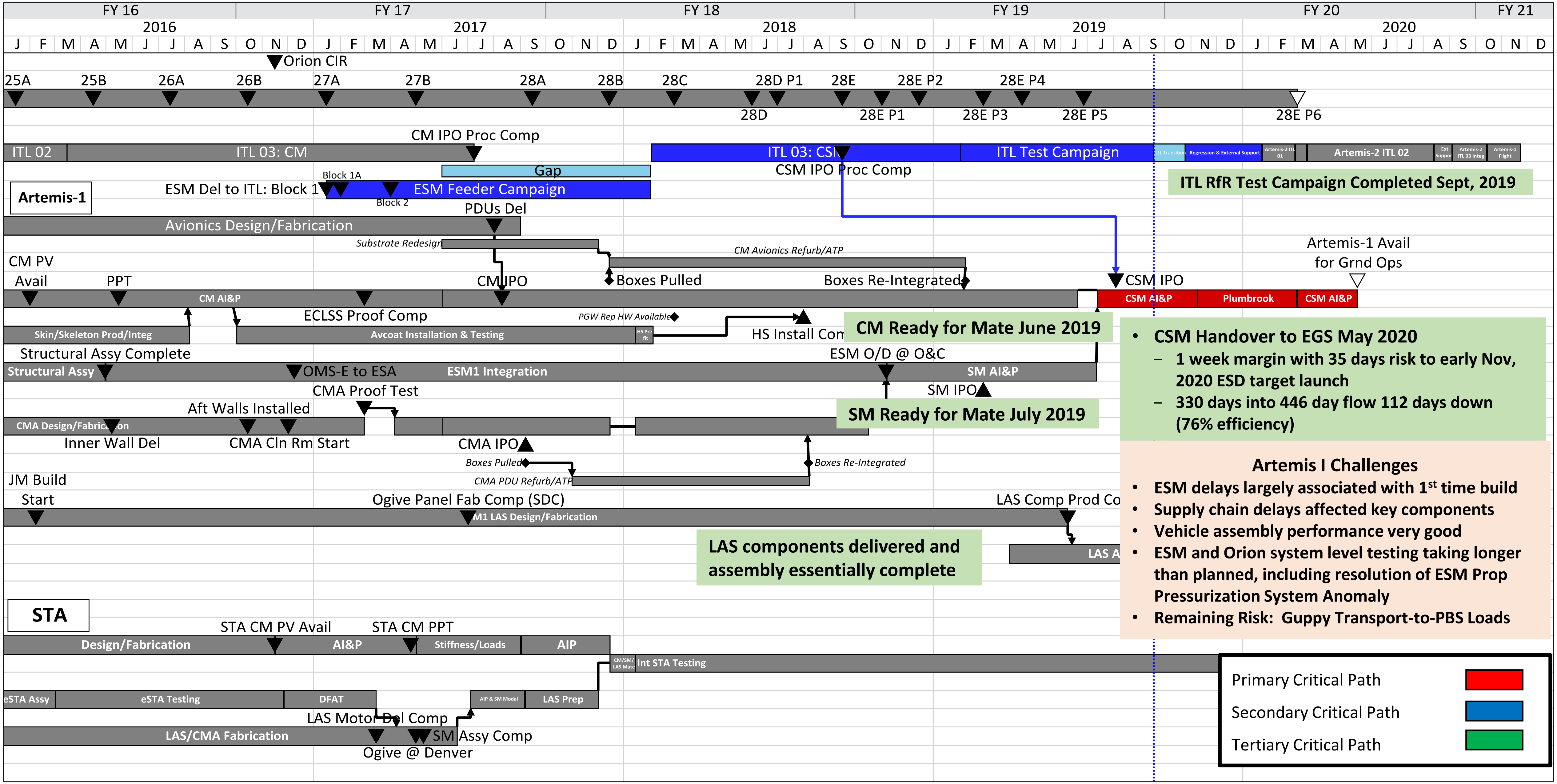
- The “Green Run” is a series of tests that will demonstrate the capability of the Core Stage Main Propulsion Systems (MPS), and related integrated systems such as the Core Stage Engines (CSEs), Core Stage Engine Controllers (CSECs), Thrust Vector Control System (TVC) and the associated Core Stage Avionics
  - A Modal Test will also be conducted prior to Green Run to gather sufficient data to allow post-test dynamic model validation
- The Green Run test series is formally identified as Protoflight testing since it is a combination of both Qualification and Acceptance test of the system functionality of a Flight Vehicle
- The overall purpose of the Green Run test is as follows:
  - Protoflight verification of the Core Stage MPS
  - Demonstration of selected Core Stage systems integrated functionality and performance which will be used for model validation/verification and requirements verification
  - Dynamic response data gathering for model correlation

Green Run is the only integrated test planned to verify the Core Stage as a system, is a necessary part of design certification, prior to final processing for the all-up flight test

ARTEMIS I
CREW MODULE / SERVICE MODULE

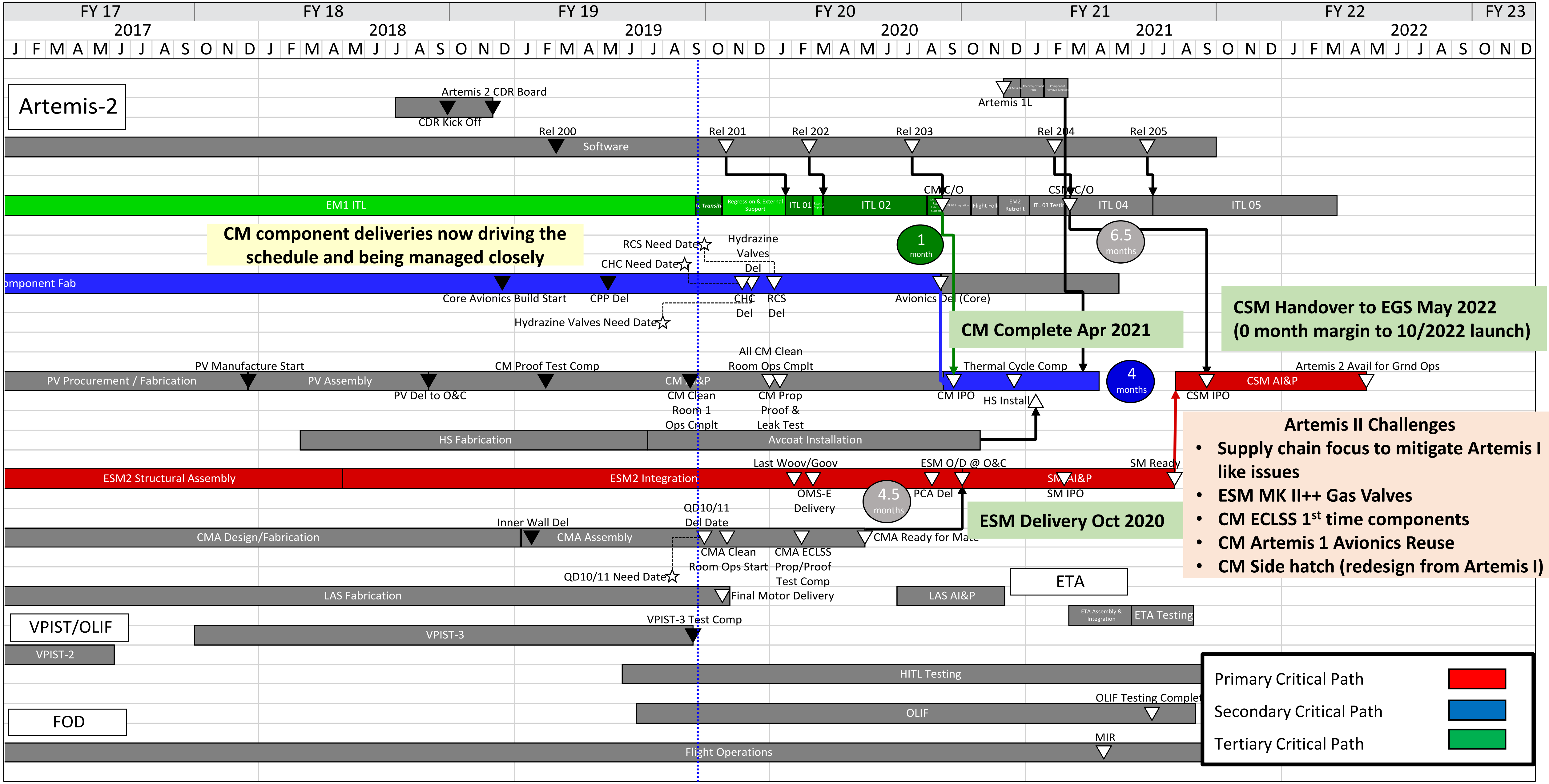


Orion Artemis I Critical Path



Orion Critical Path Summary Schedule (EM1)

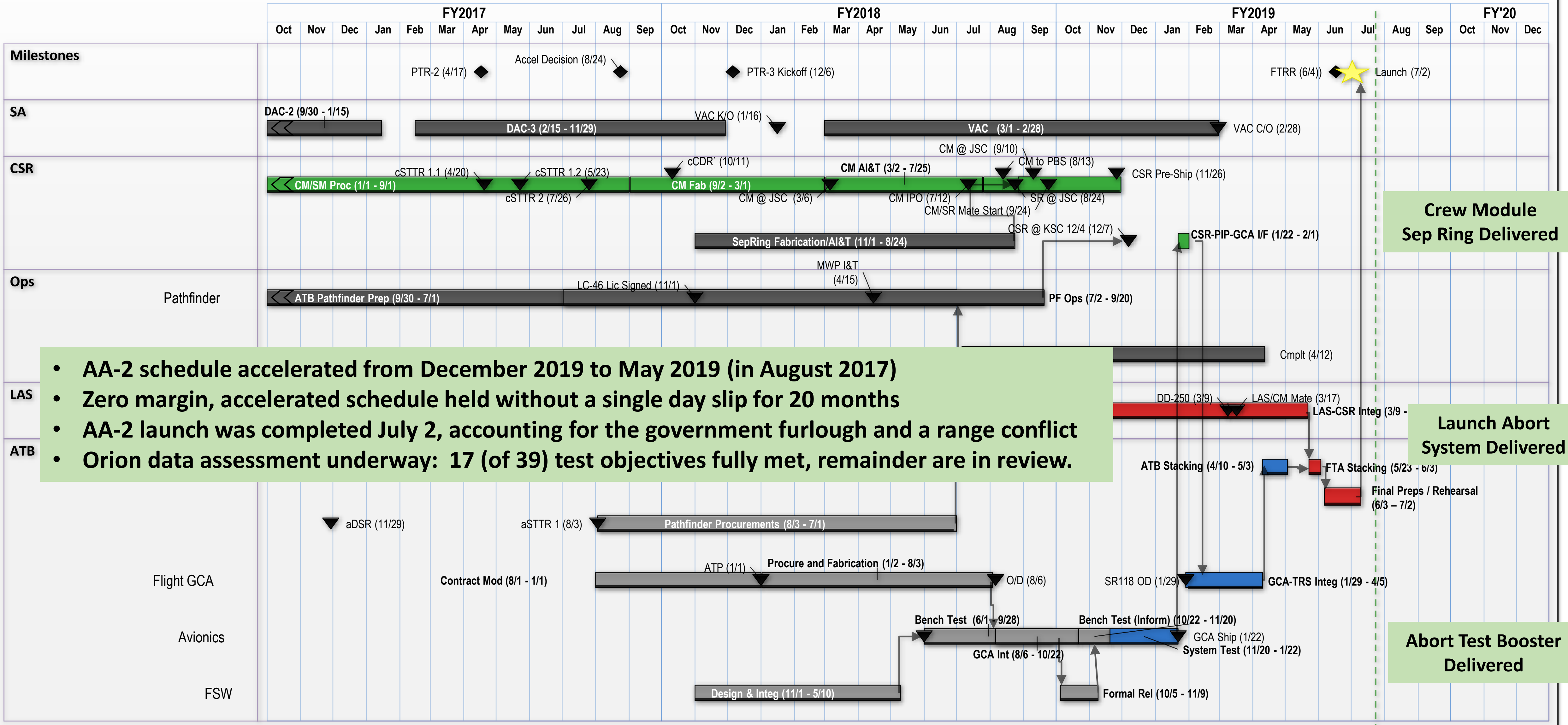
Orion Artemis II Critical Path



Orion Critical Path Summary Schedule (EM2)

AA-2 Critical Path Schedule

SUCCESSFULLY COMPLETED, 5 MONTHS EARLY



- **AA-2 schedule accelerated from December 2019 to May 2019 (in August 2017)**
- **Zero margin, accelerated schedule held without a single day slip for 20 months**
- **AA-2 launch was completed July 2, accounting for the government furlough and a range conflict**
- **Orion data assessment underway: 17 (of 39) test objectives fully met, remainder are in review.**

Crew Module Sep Ring Delivered

Launch Abort System Delivered

Abort Test Booster Delivered

Tertiary Critical Path | Secondary Critical Path | Primary Critical Path | IPT | Facility

ORION DISCUSSION TOPICS

- Budget Required to Make 2024
  - Orion FY20 ($70M), FY21 ($90M) and FY23 ($50M) overguides above current appropriations levels required to support the Artemis/Lunar 2024 schedule; Submitted as part of PPBE
  - Can phase FY20 spending for 6 months without impact; Past this, will prioritize Artemis I and II; Artemis III schedule likely affected without overguide
  - “Bulk Component Procurements” to minimize total cost affected; Potentially “non-linear” impacts
- ESA Exploration Commitment
  - ESM is currently in Orion’s critical path for all Artemis missions
  - Agreements in place for Artemis I and II, and long lead Artemis III and IV procurement
  - Need agreement for Artemis III - VI as part of this year’s 2019 ESA Ministerial Cycle. Deadline imminent
    - NASA’s lunar plan changes have complicated negotiations; Largest remaining issue is ESA element launch
    - Orion has no funded backup plan; Best option is likely to procure ESMs directly from Airbus. Requires procurement actions (6ish months lead time) and additional funding on the order of $350+M per year
- Supplier base is critical and is affecting both US and ESA manufacturing efforts
- Artemis III includes the first demonstration of rendezvous and docking in lunar orbit

RECOMMENDATIONS AND FINDINGS

2 PROPOSED NAC RECOMMENDATIONS

2 PROPOSED NAC FINDINGS

2 HEO COMMITTEE FINDINGS

HEO Committee Proposed NAC Recommendation (actionable):

Short Title of Recommendation: Human Lunar Lander Development for Safety

Recommendation:

NASA should review, with an acceptable team, the requirement for in flight testing of the HLS. Serious consideration should be given to demonstrating through flight test the ability to deorbit, land on, and ascend from the lunar surface under the expected physical and environmental conditions.

Major Reasons for the Recommendation:

A critical step in the development of the Human Landing System is the plan for human flight certification and its execution.

While there may not be a single correct or acceptable approach, systems developed for human space flight in the past have found that uncrewed end-to-end flight tests have been extremely valuable. Partial or ground testing may be options but the HEO committee strongly recommend flight testing.

Consequences of No Action on the Recommendation:

Inadequate design may not be uncovered prior to human use.

HEO Committee Proposed NAC Recommendation (actionable):

Short Title of Recommendation: Longevity of the International Space Station

Recommendation:

Perform an analysis of the safe and useful life of the ISS past 2028 with emphasis on the structure and other critical systems that cannot be replaced on orbit.

Major Reasons for the Recommendation:

An engineering analysis has been performed that shows the ISS can operate safely until 2028. The HEO committee believes a LEO platform to continue research for deep space, long duration missions will be needed past 2028. Enabling commercial LEO platforms and services should remain NASA's goal, but the Agency should understand the safe remaining life of the ISS in case the commercial platforms and services are not available by 2028.

Consequences of No Action on the Recommendation:

NASA will not have critical information necessary to making an informed decision about ISS life extension

HEO Committee Proposed NAC Finding (not actionable):

Short Title of Finding: Supporting $1.6B proposed budget for 2020

Finding:

The HEO Committee believes NASA has done a credible job estimating the 2020 funding total for Artemis to meet its goals for 2024. $1.6B is considered a reasonable estimate of the first-year costs toward the 2024 landing.

The HEO Committee acknowledges that even with the full 2020 funding request of $1.6B, accomplishing planned activities by 2024 will be aggressive, challenging, and difficult. The HEO Committee applauds NASA not raiding other Directorate budgets to fund the Artemis program.

An aggressive drive toward the 2024 deadline has prompted a sense of urgency within NASA to meet its goal. Programs, hardware and deliverables are proceeding at an unprecedented since Apollo, on or ahead of schedule. Related technology advances are proceeding rapidly.

We believe proceeding without this funding level in 2020 will result in unacceptable risk to schedule and mission.

Additionally, funding should be provided in a timely manner in order to avoid schedule slip and to maintain the current impressive momentum within the program.

The committee therefore endorses the 2020 and follow-on budget request and recognizes it to be the top priority and threat to the success if the Artemis program.

<u>HEO Committee proposed NAC Finding (not actionable)</u>:

Short Title of Finding:

NASA should be mindful of competing with industry in LEO commercialization.

Finding:

NASA has unparalleled brand value and significant resources with which nascent industry entities in the commercial LEO market are unable to compete for the same potential customers.

NASA’s recent initiatives to stimulate demand for a LEO market for which it will be one of many customers are laudable. But care must be taken to prevent unintentional consequences. For example: highly subsidized rates for accommodations aboard the ISS for Private Astronaut Missions may stimulate demand in the short term, but the ability to simply “purchase” these accommodations from NASA will not facilitate acquisition of the knowledge necessary for longer term operation in LEO by non-NASA platform providers. If NASA provides a heavily subsidized fee-for-service option leading up to the transition from a government to commercial platform, the operating entity will not have gained the necessary knowledge and experience to independently keep astronauts safe and well during their stay.

HEO Committee Finding on Schedule

The setting of a near term schedule goal (landing on the moon by 2024) has led to a change in the culture and streamlined decision-making, new acquisition methods, etc., and should keep it up even if the schedule slips

HEO Committee Finding on LSP

The service attitude and culture of the LSP are commendable to build a team that collaborates with multiple parties to achieve a launch goal. We believe that the Artemis Program (all the elements such as SLS, Orion, HLS, Gateway, et. al.) should study the way LSP operates and use the applicable processes and attitude and culture as much as is practical.

And the EVA Chief Engineer is a woman...

And the ISS Chief Engineer is a woman...

And the Ground IV is a woman . . .

And the head Flight Director is a woman...

And the public affairs speaker is a woman . . .

And the manager of the ISS vehicle office is a woman...

And the Branch Chief of Robotics Operations is a woman . . .